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Research on Dynamic Interactive Design Strategies for Museum Exhibitions from the Perspective of Affective Computing

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Abstract

With the deepening digital transformation of museums, their development focus has shifted from the singular application of technology to the in-depth exploration of audience emotional resonance. The maturation of affective computing technology provides a new pathway for this shift. This paper aims, from a design studies perspective, to explore how affective computing can empower the dynamic interactive design of museum exhibitions. Through literature review and case analysis, a design framework comprising three core strategies—"Dynamic Narrative Reconstruction," "Adaptive Interactive Adjustment," and "Multi-Sensory Collaborative Immersion"—is constructed. This framework aims to translate emotional data into specific design parameters, promoting the evolution of museum exhibitions from static information delivery ("one-size-fits-all") to dynamic emotional dialogue ("tailored to each individual"), thereby offering theoretical reference and methodological support for the practice of "integration of art and technology."

Keywords

Affective Computing, Museum Exhibition, Dynamic Interaction, Design Strategy, Integration of Art and Technology

1. Introduction

Museums, as important venues for cultural heritage and public education, are undergoing a profound digital transformation. Their exhibition paradigm no longer satisfies itself with mere artifact display and label descriptions but pursues the construction of an experiential space capable of stimulating audience emotional resonance and deepening cultural understanding. In this context, Affective Computing—a computational technology aimed at recognizing, interpreting, and responding to human emotions—offers new technical possibilities for museums to achieve personalized, deep-level interactive experiences.

However, a prevalent issue in current practice is the disconnection between technology and artistic expression or emotional needs. Many digital projects either fall into the trap of "technological spectacle," featuring dazzling interaction forms with hollow content, or remain at the stage of "one-way information push," failing to make dynamic adjustments based on the audience's real-time emotional state. The core dilemma lies in the lack of a design-led methodology that systematically translates affective computing technology into concrete interactive design.

Therefore, this study, grounded in the field of design studies, focuses on the following question: How to construct a set of effective design strategies that can organically integrate affective computing technology into the dynamic interactive design of museum exhibitions, thereby enhancing their emotional impact and communication efficacy. This paper will subsequently elaborate on the relevant theoretical foundations, construct core design strategies, and verify their feasibility through typical scenarios, aiming to provide innovative design approaches for the digital practice of museums.

2. Current Research Status at Home and Abroad

The application of affective computing in museums is becoming an interdisciplinary hotspot, showing an overall trend of parallel development in theory and practice, and the blending of technology and humanities.

Foreign research is relatively advanced both in theory and practice. Theoretically, based on psychological emotion appraisal theories and combined with multimodal emotion recognition technologies (facial recognition, physiological signals, etc.), user emotion computation models are being constructed, with growing attention to data ethics. In practice, projects such as the "Emotion Loader" at Finland's Kiasma Museum, which transforms audience facial expressions into artistic creations; Belgium's "Sense Shifting" project, which externalizes physiological signals into environmental light and shadow; and Norway's Munch Museum's "Sensitive Pictures" project, which combines self-reporting and machine emotion analysis to explore deep dialogue between audience and art, have emerged.

Domestic research, on the other hand, emphasizes the combination of technology and local cultural dissemination. Theoretically, it often employs the three-level theory of emotional design as a framework, exploring integration with new technologies like Mixed Reality (MR) and AI-Generated Content (AIGC), aiming to lower the barrier to understanding traditional culture. In practice, AI digital human docents and "emotion recognition + dynamic content adaptation" are two main directions, providing personalized guided tours by analyzing user emotions to achieve a "tailored" viewing experience.

Overall, the research trend is shifting from technology-driven to more mature experience-driven approaches. However, current research still faces challenges such as insufficient study of group social interaction, technological ethics and data privacy, and high deployment costs. Future development will focus on more accurate understanding of complex emotions, social interactive design supporting group sharing, and, under the safeguard of an ethical framework, promoting the advent of a new era for museums rich in humanistic care.

3. Theoretical Foundations of Affective Computing and Dynamic Interactive Design

3.1 The Technical Core and Design Interface of Affective Computing

Affective Computing was first systematically elaborated by Professor Picard in 1997, with its core lying in endowing computers with the ability to recognize, understand, and even express emotions. In the museum context, non-invasive emotion recognition technologies constitute the key source of design feedback. These mainly include: Facial Expression Recognition: Analyzing audience facial muscle movements via computer vision to judge basic emotions like pleasure, surprise, and confusion. Speech Emotion Analysis: Extracting features such as tone and rhythm from voice interactions during guided tours to identify emotional states. Gesture/Pose Analysis: Using devices like motion-sensing cameras to analyze audience body posture, gestures, and movement trajectories to infer interest and engagement levels.

It is crucial to emphasize that these technologies are now highly productized and modularized (e.g., mature SDKs provided by platforms like Baidu AI Open Platform, Face++). Designers do not need to delve into algorithmic details but should treat them as a callable “black box,” focusing on how their output data (e.g., a “pleasure” score) can serve as design input parameters to drive changes in interactive content.

3.2 The Artistic Principles of Dynamic Interactive Design

Technology itself is neutral; its value must be presented through artistic design. Dynamic interactive design must be built upon solid artistic principles: Narrative Space Theory: The museum space itself is a narrative field. Dynamic interaction breaks the limitations of linear narrative, allowing storylines to branch and reorganize based on audience behavior and emotions, creating non-linear, personalized narrative experiences. Gestalt Psychology: Emphasizes that human perception of things is holistic. In dynamic interaction, it is necessary to holistically consider how elements like light, shadow, color, sound effects, and space work together to form an “emotional field” that allows the audience to have a Gestalt experience. Chinese Traditional Aesthetics - “Theory of Artistic Conception (Yijing)”: Zong Baihua, in Strolling in Aesthetics, emphasizes that the interplay of “void and substance” is key to creating artistic conception. This provides supreme guidance for dynamic interactive design: the application of technology (substance) should serve the creation of artistic conception (void). For example, triggering dynamic effects on specific parts of an artifact through the audience’s “gaze” can use “blank space” to stimulate the audience’s cultural imagination, rather than resorting to force-fed information.

In summary, the theoretical foundation of this research lies in using affective computing technology as the “sensor” and “regulator,” and artistic principles such as narrative space theory, Gestalt psychology, and the theory of artistic conception as the “navigator” and “aesthetic criteria,” together forming the theoretical and practical framework for dynamic interactive design.

4. Core Design Strategies for Dynamic Interaction in Museum Exhibitions

Based on the above theoretical integration, this paper proposes the following three core design strategies, aiming to systematically address the integration of affective computing and exhibition design.

4.1 Strategy 1: Dynamic Narrative Reconstruction Based on Emotion Recognition

The core of this strategy is to treat emotion as a real-time editing variable for the narrative flow, changing "people follow the line" to "the line follows the people."

First, construct an "Emotion-Narrative Node" mapping library. During the exhibition planning stage, deconstruct the core narrative into multiple independent narrative nodes (e.g., "artifact discovery," "craftsmanship decryption," "historical context," "cultural symbolism"). Each node is associated with specific emotional states.

For instance, when the system recognizes an audience member showing a "curious" expression towards a bronze artifact, it can automatically trigger the 3D animation demonstration node for its casting process. If "confusion" is detected, it can dynamically simplify textual descriptions, highlight related exhibits, and provide graphic aids. London's V&A Museum has experimented in some of its exhibitions with dynamically adjusting gallery lighting and music based on collective audience emotion data, indirectly influencing the narrative atmosphere.

4.2 Strategy 2: Adaptive Interactive Adjustment for Multi-User Groups

This strategy aims to address the experience gap caused by differences in cognitive habits and emotional needs among different audience groups (e.g., elderly, teenagers, professional researchers).

Adopt a "preset profile + real-time emotion" composite judgment model. When an audience member enters (e.g., via ticketing system) or actively chooses, assign them a basic interaction mode. For example, enable a "low-intensity, high-companionship" mode by default for elderly audiences, featuring audio guides, enlarged fonts, and slow-paced animations; activate a "high-intensity, gamified" mode for teenage audiences, including AR treasure hunts and puzzle tasks. On top of the basic mode, superimpose real-time emotional feedback for fine-tuning. For example, in the "low-intensity" mode for elderly audiences, if the system continuously detects "low interest," it can automatically push audio stories about closely related artifacts they might find interesting to re-engage attention. The implementation of this strategy relies on lightweight integration between the museum's existing user management system and emotion recognition APIs, presenting low technical barriers and high feasibility.

4.3 Strategy 3: Multi-Sensory Collaborative Emotion Immersion Enhancement Strategy

This strategy focuses on creating and amplifying specific emotional atmospheres by integrating the audience's visual, auditory, and even tactile senses through cross-sensory channel artistic design.

Conduct in-depth analysis of the cultural attributes and emotional tone of the exhibits themselves (e.g., the "solemnity" of bronze, the "elegant charm" of porcelain, the "ethereal quality" of calligraphy and painting), and design matching multi-sensory schemes for them. Creating Solemnity: In the bronze exhibition area, complement with deep, gradient cool-toned lighting and introduce low-frequency, subtle vibration feedback (via handheld devices or modified display stands) to visually and somatically reinforce the weight and divinity of the artifacts. Creating Elegant Charm and Tranquility: In the porcelain exhibition area, employ soft warm light projection and play minimalist environmental sound effects simulating natural white noise (e.g., wind through bamboo, light rain), jointly constructing an aesthetic space where audiences can appreciate artifacts in peace.

The entire creative philosophy of the renowned art team TeamLab is built on constructing “immersive worlds.” Their works perfectly integrate vision, sound, and interaction through digital technology, fully demonstrating the immense potential of multi-sensory collaboration for emotional arousal.

5. Feasibility and Validation in Typical Scenarios

5.1 Technical Feasibility and Integration Path

The strategies proposed in this paper are not castles in the air; their implementation relies on the currently prevalent technology ecosystem. Designers can use mature engines like Unity or Unreal Engine to build interactive content and logic, obtain real-time emotional data by calling commercial emotion recognition APIs (as mentioned earlier), and integrate them into the museum’s existing digital guide app or on-site interactive terminals. The entire technical path is clear, with well-defined module responsibilities, requiring no disruptive innovation and possessing high engineering feasibility.

5.2 Construction and Logical Deduction of Typical Interactive Scenarios

To concretely demonstrate the application of the strategies, we construct a typical interactive scenario for “Dunhuang Flying Apsaras Murals.”

The initial state is a static display of the mural with distant, ethereal Buddhist chanting as the ambient sound effect. The interaction trigger is the system camera (anonymized, not storing individual biometric information) detecting that Audience A’s gaze behavior on the “Flying Apsaras” image exceeds a 5-second threshold, while simultaneously recognizing a significant increase in the “pleasure” and “interest” indicators of their facial expression.

Applying Strategy 1 and Strategy 3. First, perform dynamic narrative reconstruction: the system determines to trigger the narrative node for “cultural symbolism of the Flying Apsaras.” Then, design multi-sensory collaborative immersion: the ribbons of the “Flying Apsaras” in the mural begin to flow slowly following physical laws, simulating the artistic conception of “Wu’s ribbons flowing in the wind”; meanwhile, extremely subtle, soothing wind sounds are blended into the background Buddhist chanting, and the flowing trajectory and color saturation of the ribbons are visually enhanced through projected lighting effects.

Figure 1. Effect Diagram of Typical Interactive Scenario "Dunhuang Flying Apsaras Mural"

This interaction does not directly state the religious meaning or artistic value of the "Flying Apsaras." Instead, it triggers the "ribbon animation" through the respectful act of "gaze," using the Chinese aesthetic technique of "interplay of void and substance" to transform the cultural imagery of "the beauty of flight" into a perceivable emotional experience, effectively validating the aforementioned strategies' effectiveness.

5.3 Expected Efficacy and Evaluation Dimensions

The effectiveness of the strategies can be verified through a mixed evaluation system in future empirical research. Quantitative indicators may include: average dwell time, fluctuation rate of emotion curves based on expression recognition, and interaction task completion rate. Qualitative indicators can be obtained through subsequent semi-structured interviews, focusing on the audience's perception of artistic conception and degree of cultural resonance. For example, interview descriptions like "When the ribbons started to move, I felt as if I could sense the ancients' longing for flight and the romance of their art" would be direct evidence of the strategies' success.

6. Conclusion and Outlook

Addressing the core issue of the missing emotional dimension in the digital exhibition of museums, this study constructs a dynamic interactive design framework composed of three strategies: "Dynamic Narrative Reconstruction," "Adaptive Interactive Adjustment," and "Multi-Sensory Collaborative Immersion." Its main innovation lies in systematically transforming affective computing from a cutting-edge technology into a design-led, operable design thinking and methodology, emphasizing the navigational role of artistic theory in technological application.

This study still has limitations, primarily in that the strategic framework requires validation of its universality and long-term effects through large-scale, long-cycle field applications. Looking ahead, with the evolution of affective computing technology (e.g., the application of portable EEG devices), the precision and depth of dynamic interaction will further improve. Simultaneously, data privacy and design ethics must become the focus of forward-thinking. Future research needs to strive for a balance between creating immersive experiences and protecting audience privacy, and formulate corresponding industry design standards to guide the "emotional" transformation of museums towards a healthy and responsible direction.

Project

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